

Evaluation of chemically controlling the collembolan *Bourletiella hortensis* on germinating Sitka spruce and western hemlock in the nursery

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Three concentrations of the insecticides diazinon, fonofos, malathion, and oxamyl and one concentration of the herbicidal mineral oil Shell AWK No. 1® were tested on Sitka spruce [*Picea sitchensis* (Bong.) Carr.] and western hemlock [*Tsuga heterophylla* (Raf.) Sarg.] for controlling the collembolan *Bourletiella hortensis* (Fitch) in nursery trials in 1972 and 1973. All insecticides were effective against the insect, but low spring populations of the collembolan prevented full evaluation of the trials. A 4-m diazinon-sprayed surround was adequate to keep the insect from migrating to adjacent plots. Certain nursery practices, such as application of the herbicidal mineral oil Shell AWK, the herbicide propazine, and sodium fluosilicate for weevil control, temporarily suppressed *B. hortensis* populations but did not provide effective control against this insect. Shell AWK, applied when the radicle was emerging from the seed, was apparently phytotoxic to Sitka spruce.

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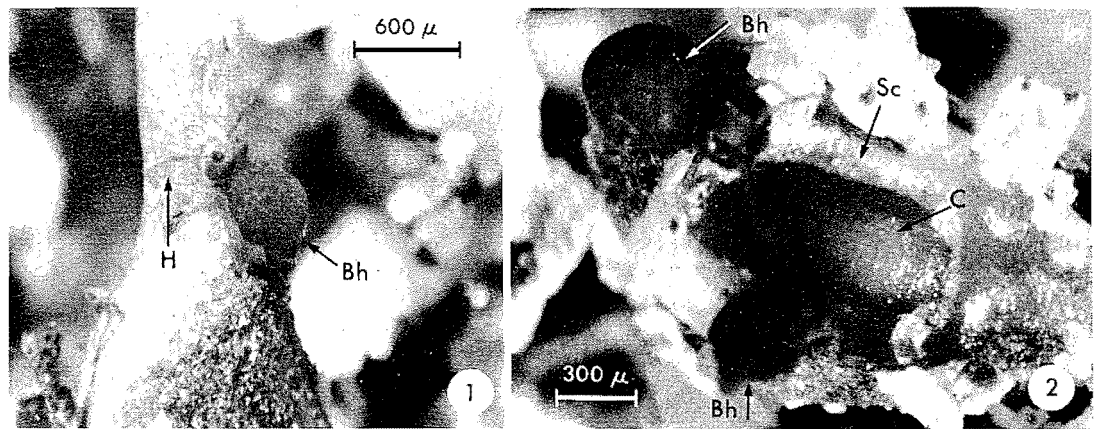
En 1972 et 1973, en pépinière, les auteurs essayèrent trois concentrations des insecticides diazinon, fonofos, malathion et oxamyl et une concentration de l'huile minérale herbicidale AWK No. 1 Shell® sur l'Épinette de Sitka [*Picea sitchensis* (Bong.) Carrière] et la Pruche occidentale [*Tsuga heterophylla* (Raf.) Sarg.] pour lutter contre le Collembole des jardins, *Bourletiella hortensis* (Fitch). Tous ces insecticides s'avérèrent effectifs contre l'insecte, mais les Collemboles, trop peu nombreux au printemps, ne permirent pas d'évaluer pleinement les essais. Le long des limites des parcelles, une bande périphérique de 4 m arrosée avec de l'insecticide diazinon suffit à empêcher les insectes d'émigrer dans les parcelles adjacentes. Dans certaines pépinières, on utilisait l'huile minérale herbicidale AWK Shell et l'herbicide propazine, et aussi le fluosilicate de sodium contre les Charançons, et ceci produisait l'effet secondaire de supprimer temporairement les populations de *B. hortensis*, mais ne s'avèrent pas effectifs pour lutter contre cet insecte. L'AWK Shell se révélait apparemment toxiques à l'Épinette de Sitka lorsqu'on les appliquait quand la racine émergeait de la graine.

Introduction

The collembolan *Bourletiella hortensis* (Fitch) [= *B. signata* (Nicolet)], a pest of many agricultural crops (Edwards and Heath 1964), has damaged lodgepole pine (*Pinus contorta* Dougl.) and larch (*Larix* sp.) in the United Kingdom (Bevan 1965). The presence of large numbers of *B. hortensis* in British Columbia forest nurseries during the summer, accompanied by low seedling survival during some years, prompted us to conduct a prelimi-

nary laboratory experiment to determine if there was a relationship between the presence of the collembolan and seedling survival. In this experiment, *B. hortensis* reduced the number of germinants of Engelmann spruce (*Picea engelmanni* Parry), Sitka spruce [*P. sitchensis* (Bong.) Carr.], white spruce [*P. glauca* (Moench) Voss], and western hemlock [*Tsuga heterophylla* (Raf.) Sarg.] by 20, 39, 22, and 37%, respectively. Seedlings were mainly attacked just before and at the 'drumstick' stage, i.e., when the hypocotyl was straightening out and before the seed coat was shed (Figs. 1 and 2).

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FIGS. 1 and 2. *Bourletiella hortensis* feeding on germinating Sitka spruce and western hemlock, respectively. Note: Bh, insect; C, exposed cotyledons; H, hypocotyl damage; Sc, seed coat damage.

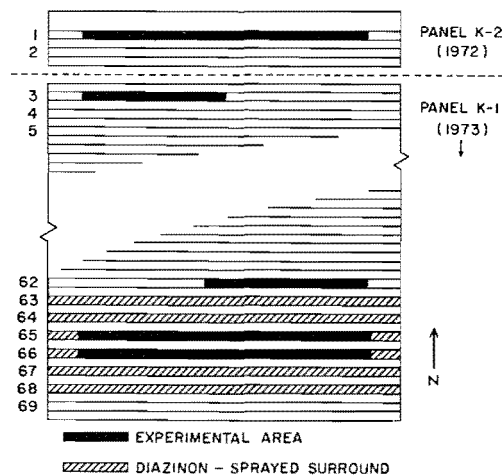


FIG. 3. Field layout of experimental beds in the Koksilah Nursery.

Although a number of insecticides can control Collembola, quantitative field data were not available on the effect of selected insecticides on the population dynamics of *B. hortensis* or on the insecticide phytotoxicity to important British Columbia conifer species. Nursery trials were therefore undertaken to determine the effects of five pesticides on *B. hortensis* populations and on the survival of Sitka spruce and western hemlock seedlings. Four insecticides were previously screened in a greenhouse phytotoxicity experiment (Illytzyk and Marshall 1974) for future field trials. Three of these (diazinon, fonofos, malathion) are organophosphorus insecticides and were effective against

other species of Collembola (Spencer 1968; Thompson and Gore 1972); the fourth (oxamyl) is a carbamate and was included as an alternative for populations that might develop resistance to the organophosphorus insecticides. The herbicidal mineral oil Shell AWK No. 1[®] was also tested for its possible insecticidal effects, as other herbicides have temporarily reduced certain collembolans (Curry 1970; Edwards 1970).

Materials and Methods

Experiment 1 (1972)

This experiment was carried out at the Koksilah Nursery, Duncan, British Columbia. On April 28, the field was cultivated; on May 3, bed 1 in panel K-2 (Fig. 3) was tractor-sown to low elevation (below 433 m) Sitka spruce and western hemlock.² Three rows on the right side of the bed were sown to Sitka spruce, and three on the left side, to western hemlock. The center row of the usual seven-row nursery bed was not sown. Enough seed was sown to give about 326 germinants per metre-row. Watering, weeding, and other nursery practices, including an application on May 15 of herbicide Shell AWK No. 1 at the rate of 675 l/ha, were those generally used by the British Columbia Forest Service (van den Driessche 1969).

Seventy 1.5 m-long plots were staked out along the bed and the four insecticides, in three concentrations (Table 1), were applied on May 19, when most of the germinants had reached the 'root stage' (radicle penetrating the soil). Each of the 12 insecticide treatments (4 insecticide × 3 concentrations), replicated 5

²British Columbia Forest Service seed lot numbers 1012 (Sitka spruce; Tofino-Ucluelet Peninsular 49° N, 125°50' W) and 960 (western hemlock; Sayward Valley 50°20' N, 125°55' W).

TABLE 1. Insecticides and their equivalent application rates of active ingredients (*a.i.*)

Insecticide	Equivalent rate of <i>a.i.</i> , kg/ha		
Diazinon, [<i>O,O</i> -diethyl <i>O</i> -(2-isopropyl-6-methyl-4-pyrimidinyl)phosphorothioate]	0.56	1.12	2.24
Fonofos, [<i>O</i> -ethyl <i>S</i> -phenyl ethyl phosphonodithioate]	2.24	4.48	6.72
Malathion, [diethyl mercaptosuccinate, <i>S</i> -ester with <i>O,O</i> -dimethyl phosphorodithioate]	4.48	6.72	8.96
Oxamyl, {methyl <i>N,N'</i> -dimethyl- <i>N</i> -[(methylcarbamoyl)-oxy]-1-thiooxamimidate}	1.12	2.24	3.36

times, and a check, replicated 10 times, were assigned to a specific plot in the bed by using a computer program containing a pseudorandom-number generator.

Insecticides were applied as a water-base emulsion at the rate of 935 l/ha, by using a hand sprayer and a 1-m-high plastic shield to prevent contamination of adjacent plots.

Collembolan numbers were estimated by a grease-film technique. Petrolatum® was thinly applied to 50-cm² plastic films, which were then placed petrolatum-face downward and fastened with nails at four corners to the soil surface. After 1.5 h, grease films were removed and placed in petri dishes, and collembolans were counted in the laboratory with a binocular microscope. Before insecticide application, 10 grease films were randomly placed in the experimental area. After insecticide application, at intervals of about 2 weeks, nine films per treatment (three placed randomly in each of three replicates for each insecticide concentration) were placed on the beds.

All seedlings of each species within the plot were counted on September 29, 1972, and on July 31 of the next summer, for overwintering survivors. The data for each tree species were analysed separately as a completely randomized design and the significance ($P \leq 0.05$) of each mean difference was determined by Newman-Keuls' test (Kirk 1968).

Collembolan data from the different insecticide concentrations (Table 2) were analysed in the same manner as for each tree species, and a linear regression of seedling survival on collembolan counts was carried out where plot information was available for the two variables.

Experiment 2 (1973)

Experiment 2 was conducted in panel K-1 (Fig. 3), tractor-sown on May 1 only to Sitka spruce (seed lot 1012) in 75 plots, each 6.1 m long (4 insecticides $\times$ 3 concentrations $\times$ 5 replications + 5 'insecticide' Shell AWK + 10 checks). Five pesticides were used: the four insecticides shown in Table 1 as water-base emulsions at the rate of 935 l/ha for each concentration and Shell AWK^a applied alone at the rate of 675 l/ha.

^aThe herbicide Shell AWK No. 1 (675 l/ha) was applied three different ways during this experiment: (1) as a herbicide during normal nursery practice; (2) in combination with the insecticides diazinon, fonofos, malathion, and oxamyl; and (3) alone to

Applications of the five pesticides alone were made with a tractor-mounted sprayer on May 17, and 'combined' Shell AWK was similarly applied on May 22.

Because of difficulties with experiment 1 (see Results and Discussion), thought to result from insect movement and not ineffectiveness of the insecticides, a different approach was taken in experiment 2. The control plots were separated from the pesticide-treated plots. It was recognized that the precision of the experiment might be reduced by differences between beds, though the seeder was set for the same sowing rate for all beds.

The 65 pesticide-treated plots were randomly distributed on beds 65 and 66, and a 4-m-wide surround was sprayed with diazinon (1.12 kg/ha, active ingredient (*a.i.*)) around these plots to minimize the influx of *B. hortensis* from other parts of the nursery. To test for interaction between insecticides and the herbicide Shell AWK, the 65 pesticide-treated plots were divided in the center; half of each plot was sprayed with pesticides alone, the rest with pesticide plus Shell AWK (i.e., 'combined' Shell AWK) at the rate of 675 l/ha.

Check plots (bed 62) were separated from the pesticide-treated plots on one side by the sprayed surround but not from adjacent untreated beds. They were hand-weeded to eliminate possible detrimental effects on *B. hortensis* from herbicides applied during normal nursery practices.

Watering, weeding, and other nursery practices were those generally applied by the British Columbia Forest Service. These included the following: two applications of 'normal' Shell AWK to all plots on May 11 and 15; one application of paraquat (5.7 l/ha) to all beds, except 62 (the check), in June (bed 3 on June 1 and beds 65 and 66 on June 11); one application of propazine (6 kg/ha) to all beds, except 62 (bed 3 on June 21 and beds 65 and 66 on July 24); and two applications to all plots of weevil bait (sodium fluosilicate, 5% *a.i.* at 44.8 kg/ha) on July 12 and 20.

Collembolan populations were monitored by a grease-film technique (see experiment 1) in the check plots (bed 62) and in pesticide-sprayed plots (beds 65 and 66) from April to August and in an area receiving herbicides but no insecticides (bed 3) from April to

test its possible insecticidal properties. These types of applications are henceforth referred to as 'normal' Shell AWK, 'combined' Shell AWK, and 'insecticide' Shell AWK, respectively.

TABLE 2. Effect of the four insecticides on *B. hortensis* population expressed as mean numbers per treatment per square metre

Date, 1972	Check	Insecticides, kg/ha, a.i.													
		Diazinon				Fonofos				Malathion				Oxamyl	
		0.56	1.12	2.24	2.24	2.24	4.48	6.72	6.72	4.48	6.72	8.96	1.12	2.24	3.36
May 18	160 ± 60*														
May 19															
May 29	60 ± 40	200 ± 99	40 ± 27	20 ± 20	0 ± 0	40 ± 27	20 ± 20	20 ± 20	20 ± 20	0 ± 0	60 ± 30	20 ± 20	20 ± 20	20 ± 20	
June 29	4467 ± 656	6333 ± 1122	6155 ± 695	3312 ± 781	2244 ± 352	1600 a ± 500	4955 ± 320	1177 a ± 320	1822 a ± 271	3088 ± 506	2400 ± 578	1955 a ± 477	2046 a ± 346	2046 a ± 346	

* Mean ± SE mean. The May 18 value was measured at 10 random locations before experimental plots were established. All other values are nine estimates per treatment. Means for a given date without a letter are not statistically significant from the check; those followed by the letter 'a' are significantly different from the check (Newman-Keuls' test, $P \leq 0.05$).

July. In spring, *B. hortensis* was abundant in bed 3, which was therefore useful for studying population changes.

The five inner rows of seedlings from the center 1-m section of each plot were counted on July 19. Data from beds 65 and 66 were analysed as a completely random design to determine effects resulting from insecticides (including 'insecticide' Shell AWK) and from the combination of insecticides with Shell AWK (i.e., pesticide versus 'combined' Shell AWK, Table 3). Data from pesticide-treated plots from beds 65 and 66 were analysed with data from bed 62 (check) as if from a completely randomized design to compare pesticide-treated plots with untreated plots. Significance ($P \leq 0.05$) of each mean difference was determined by Newman-Keuls' test.

Results

Collembolan Population Dynamics and Control

Bourletiella hortensis appears in the nursery in April, reaches a maximum in July, then rapidly declines in mid-September (Fig. 4). The species apparently overwinters in the egg stage since adults were not collected during the winter and numerous hatchlings appeared on soil brought into the laboratory in February and in the field in early April. During spring, the collembolan population in the nursery varied in different locations, certain areas being reservoirs for rapid population expansion. For example, in early June 1973 (Fig. 5), the *B. hortensis* population was about 100/m² in the check plot (bed 62), whereas in bed 3, about 90 m away and also without insecticide treatment, the population was about 8000/m². Bed 62 was in the middle of the freshly sown K-1 panel, but bed 3 was adjacent to an undisturbed field of rising 2-0 seedlings where there was a collembolan population.

In 1972, none of the insecticide treatments was significantly different from the check 10 days after application (Table 2, Fig. 4) because of the initial low collembolan populations at the time of insecticide application. All plots were rapidly recolonized and 1 month after application only the intermediate concentration of malathion and the intermediate and high concentrations of fonofos and oxamyl were significantly lower than the check. Generally, the average populations in insecticide-treated plots were not sufficiently lower than the check to be considered effectively controlled; therefore populations were not further monitored in the insecticide-treated plots (Fig. 4). Data are un-

TABLE 3. Mean number of seedlings per metre 4 months (1972) and 2 months (1973) after pesticide application. Values in each column without letters, or those followed by the same letter, are not significantly different ($P \leq 0.05$)

Pesticide	1972		1973, Sitka spruce	
	Hemlock	Sitka spruce	Pesticide only	'Combined' Shell AWK
Diazinon, kg/ha, <i>a.i.</i>				
0.00	31	66	88 a	88 a
0.56	37	74	37 b	18 b
1.12	37	87	47 b	20 b
2.24	27	68	65 ab	31 b
Fonofos, kg/ha, <i>a.i.</i>				
0.00	31	66	88 a	88 a
2.24	38	75	65 ab	24 b
4.48	29	76	40 b	18 b
6.72	34	51	46 b	25 b
Malathion, kg/ha, <i>a.i.</i>				
0.00	31	66	88 a	88 a
4.48	31	74	55 b	24 b
6.72	46	68	50 b	25 b
8.96	26	67	40 b	17 b
Oxamyl, kg/ha, <i>a.i.</i>				
0.00	31	66	88 a	88 a
1.12	40	72	52 b	18 b
2.24	36	77	46 b	17 b
3.36	30	69	48 b	22 b
'Insecticide' Shell AWK, l/ha				
0.00	—	—	88 a	88 a
675	—	—	50 b	18 b

available on the effects of all these insecticides⁴ on eggs of *B. hortensis*, but it appears that the insects moved from other parts of the nursery and reproduced in the insecticide-treated plots.

In the 1973 experiment, the population in the insecticide-treated plots, which were protected by a 4-m-wide diazinon-sprayed surround, did not recover and remained below 200/m² 3 months after insecticide application, while in the check plots, the population rose to over 12 000/m² (Fig. 5). *Bourletiella hortensis* population in the 'insecticide' Shell AWK plots closely paralleled that in the check plots, indicating no effect. Population reductions coincided with applications of 'normal' Shell AWK, propazine, and the first application of weevil bait (Figs. 4 and 5), but these chemicals appear

to suppress only temporarily the *B. hortensis* populations.

Seedling Survival

Table 3 summarizes the results on seedling survival, which generally showed no benefit from insecticide treatment and possible phytotoxicity from the application of 'combined' Shell AWK. The regression of seedling survival on collembolan counts was also not statistically significant. In 1972, the insecticide-treated plots, on an average, contained 11% more hemlock seedlings, but this was not significantly different from the check. For Sitka spruce, like western hemlock, there were higher seedling counts after low and intermediate applications of insecticide than in the check or higher-dosage plots, but the differences were not statistically significant. For each insecticide rate, overwintering survival was about 74% of the previous summer counts for all treatments.

In 1973, the check plots contained a significantly higher number of Sitka spruce seedlings

⁴Hatchlings, which were readily trapped in open petri dishes placed on soil brought into the laboratory in early March, did not appear when the soil was treated with 1.12 kg/ha diazinon, but it could not be ascertained whether diazinon is an ovicide or whether the insects hatched and then died.

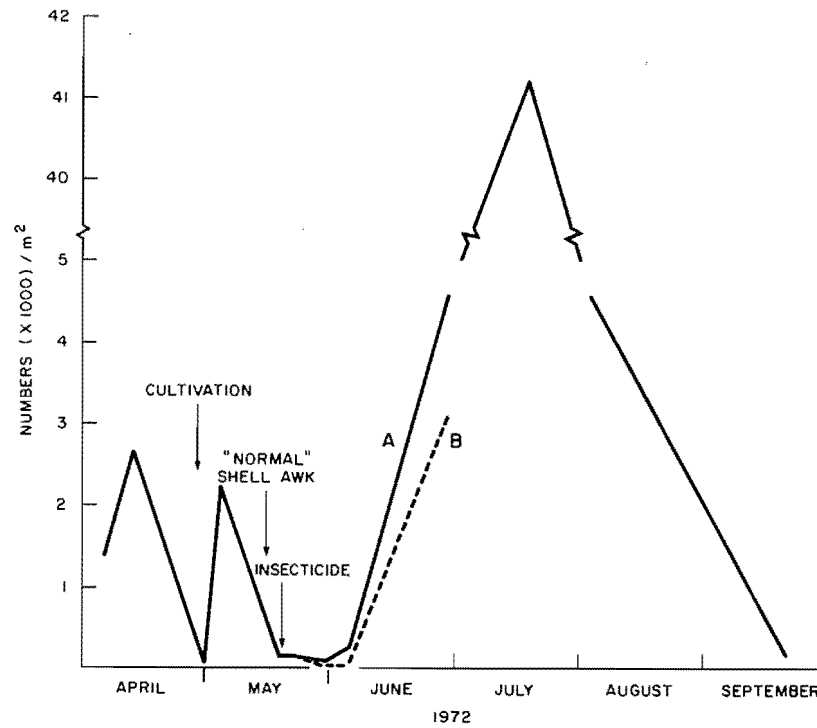


FIG. 4. Population fluctuations in *B. hortensis* in the 1972 experimental area. A, check plots; B, insecticide-treated plots.

per meter-row than most of the pesticide-treated plots. Only two of the latter (2.24 kg/ha diazinon and fonofos) equalled the check. Unfortunately, only the control plots were hand-weeded; therefore, it was unclear whether or not the reduction in the pesticide-treated plots was caused by phytotoxicity directly from herbicides, directly from insecticides, or from a combination of both.

The application of 'combined' Shell AWK (pesticide plus Shell AWK) was particularly deleterious to germinants, significantly ($P \leq 0.05$) reducing mean survival to 26% of the check. Here again, it is difficult to determine whether this reduction resulted from direct phytotoxicity of Shell AWK or from an adverse interaction of insecticide and herbicide because all plots received 'normal' Shell AWK 5 and 2 days before pesticide application (Fig. 5) and 'combined' Shell AWK was applied to the second half of these plots 5 days after pesticide application. However, the first hypothesis seems more plausible since the 'combined' Shell AWK was applied when the seedlings were entering

a stage susceptible to the chemical. Also, the 18 seedlings per metre, as opposed to 50 (Table 3, 'insecticide' Shell AWK), were 21% of the check and of the same magnitude as the other 'combined' Shell AWK (insecticides plus Shell AWK) plots, further suggesting direct phytotoxicity by Shell AWK.

Discussion

The results from 1972 indicate that because of mobility of *B. hortensis* small unprotected pesticide-treated plots are inadequate for field trials. Wallace (1967) used 1.8-m-square plots surrounded by a 30-cm-high bitumenized felt barrier that was sunk 4 cm in the ground and was periodically painted with creosote to prevent movement of *Sminthurus viridis* (L.) into and out of experimental plots. However, peat pots containing known number of seedlings, or even plastic markers, in the Koksilah Nursery attracted seagulls, crows, and pigeons, which caused much damage to seedlings near these structures. When such pots were protected from

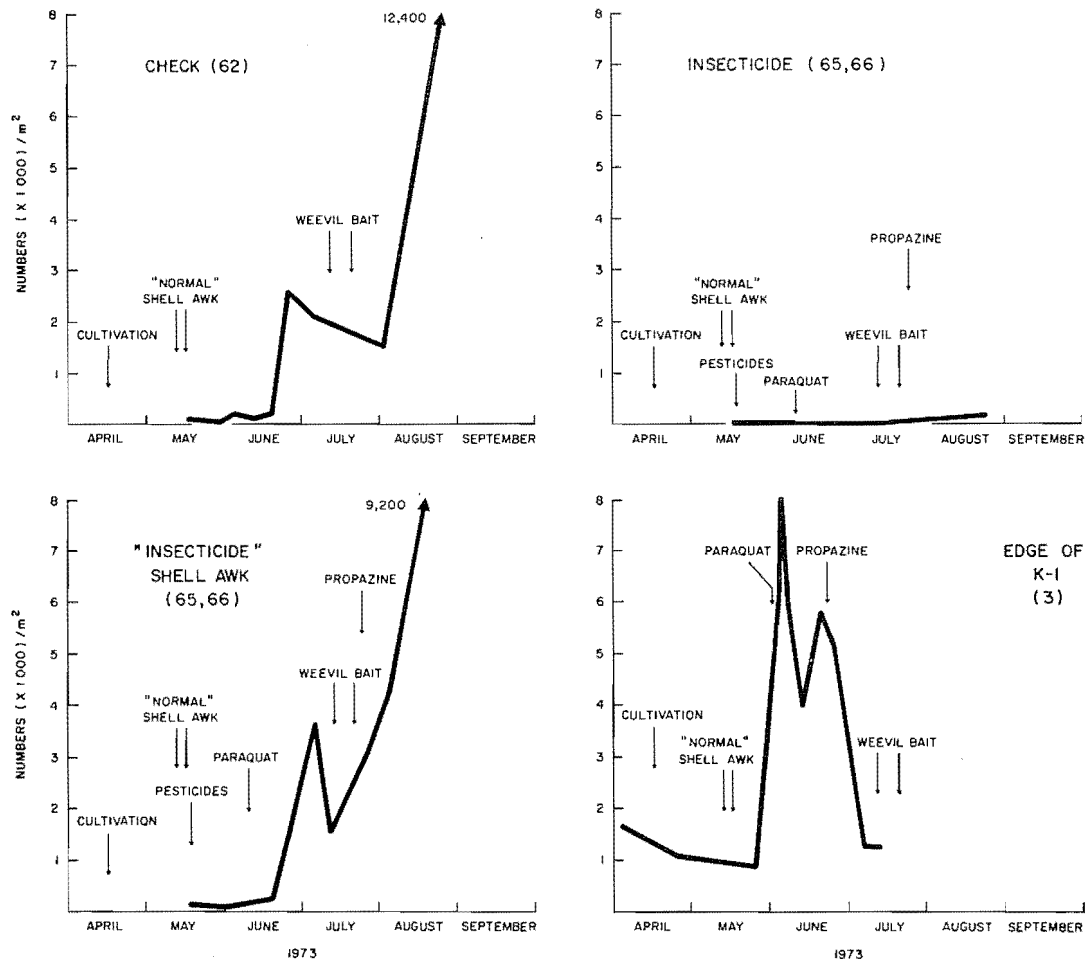


FIG. 5. Population fluctuations in *B. hortensis* at various locations in the nursery and related to some nursery practices in 1973. Pesticide treatment and associated nursery beds, in parentheses, are shown on each graph.

birds, cutworms enclosed within the barriers damaged the seedlings. Another approach was therefore adopted to restrict insect movement. The results from 1973 showed that a 4-m-wide diazinon-sprayed (1.12 kg/ha, *a.i.*) buffer was adequate to prevent migration from unsprayed to sprayed plots. However, this method of completely isolating small untreated (check) plots might be unsuitable because outward migration into the diazinon-treated surround where insects would be killed might not be balanced by inward migration.

In 1973, a single application of any of the four insecticides (diazinon, fonofos, malathion, oxamyl) controlled *B. hortensis* for at least 3 months, but benefits resulting from insect con-

trol may have been balanced by seedling phytotoxicity, especially from the herbicides paraquat and propazine that were applied to these plots. All the insecticides, depending on when they were applied, also exhibited phytotoxicity to germinating western hemlock, Sitka spruce, and white spruce in a greenhouse trial (Illytzky and Marshall 1974). Therefore, caution must be exercised in their use on germinating conifers. Unless insect populations are high enough to cause serious damage, there could be an unfavorable trade-off between phytotoxicity and insect control.

In the 1972 experiment, when there was a high collembolan population in the control plots in late June during the latter stage of germina-

tion, the rapid recolonization of the insecticide-treated plots probably nullified benefits that spraying produced. In 1973, the insect population in the check plots was initially very low and did not attain a high level because summer applications of weevil bait appeared to adversely affect *B. hortensis* in these plots.

It seems unlikely that there could have been much seedling damage before insecticide application, but this possibility cannot be discounted. Since a single application of the four selected insecticides, even at a low rate, can control *B. hortensis* throughout the summer and since there might be an adverse insecticide-herbicide interaction if insecticides are applied during the early stages of germination, insecticides should be applied immediately after sowing.

Shell AWK is normally applied at the 'root stage' of germination, and it was hoped that Shell AWK might also be effective against *B. hortensis*. Although it reduces the insect population, its effects are short-lived and its toxicity to germinants just before and at the 'cotyledon stage' (hypocotyl perpendicular and cotyledons enclosed by seed coat), when the insect population is building up, makes it an impractical chemical control for *B. hortensis* under the climatic conditions in coastal British Columbia.

The adverse effect of certain herbicides on *B. hortensis* might sufficiently disrupt the population to give partial control during the years these herbicides are used. However, in nurseries not chemically weeded, large *B. hortensis* populations during spring may have to be controlled. Experiments, in which confounding factors are removed (e.g., herbicide applications), are in

progress to study damage in relation to population levels, time of insecticide application, as well as damage in hand-weeded nurseries.

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